Summary of Locomotive Aftertreatment Applications

by

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Outline

* Summary of locomotives fitted with aftertreatment
* Application issues/challenges of installing aftertreatment in US locomotive
* European locomotives equipped with DPF
* MBTA DOC demo
* California Emissions Program (CEP)
* US-EPA / UP program to equip and demonstrate DOC in line-haul locomotive
* Application of SCR to EMD Diesel Engines at Southern California Edison's Pebbly Beach Generating Station at Santa Catalina Island, California

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Summary of Locomotive Aftertreatment Applications

Europe:

* SBB Cargo: Vossloh MaK2000BB + Hug DPF (1)
* SBB Cargo: Vossloh Mak 1700 + Hug DPF (75+)
* Eurotunnel: Vossloh MaK 1206 + scrubber wagon
  - » In the process of being retrofitted with Hug DPF & SCR

USA:

* MBTA Boston: EMD F40 + Oxycat
* UP2368 EMD SD60M + Oxycat
* UPY1378 & BNSF3703: EMD MP15DC + Hug DPF

* SCR – None on Locomotives W/ power ratings > 1,000 hp
  - » One case study of SCR on EMD engines

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Recapping Locomotive Aftertreatment Application Issues/Challenges

* Packaging and space availability
  - » AAR “Plate L” clearance diagram
* Locomotive specific issues:
  - » Shock & vibration
  - » Temperature extremes
  - » Tunnel operation environment
  - » Railroad lubricating oil considerations
* Locomotive product qualification, verification, and reliability
* Locomotive emissions useful life, emissions warranty, etc.
* Crankcase blowby considerations

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European Locomotives Equipped with Diesel Particulate Filters (DPF)

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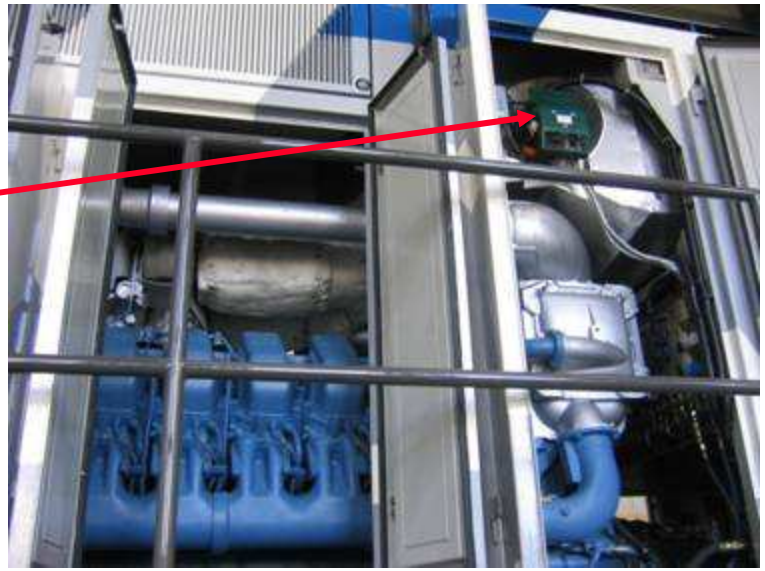
European Locomotive Applications - Background

* Several reports of European diesel locomotives equipped with particulate filters
  - » 1,500 kW (2,000 hp – GP38 equivalent) Cat-powered diesel-hydraulic freight locomotives
  - » Also one prototype 2,700 kW (3,600 hp) Vossloh freight locomotive with a MTU 20V-4000 diesel engine
    - – This prototype is the largest, most powerful diesel powered freight locomotive manufactured today in Europe

* Both equipped with Diesel Particulate Filters (a.k.a. “soot filters”) manufactured by Hug Engineering in Winterthur, Switzerland
  - » Hug is one of the manufacturers participating in the AAR/BNSF/UP-sponsored “California Emissions Program”
  - » Soot filters installed by the locomotive OEM (Vossloh) on new locomotives as requested by the customer

Vossloh 2000 Series Locomotive

* 2,700 kW (3,600 hp) MTU 20V-4000 diesel engine
* Hug DPF integrated into car body
  - » Replaced muffler
  - » Very heavy – needed to factor weight into mounting design
  - » Designed for 5 g longitudinal shock, and 3 g vertical.
  - » 2 burners to regenerate filter
* DPF offered today as an option on new locomotives in selected European markets, supported by locomotive and engine OEMs



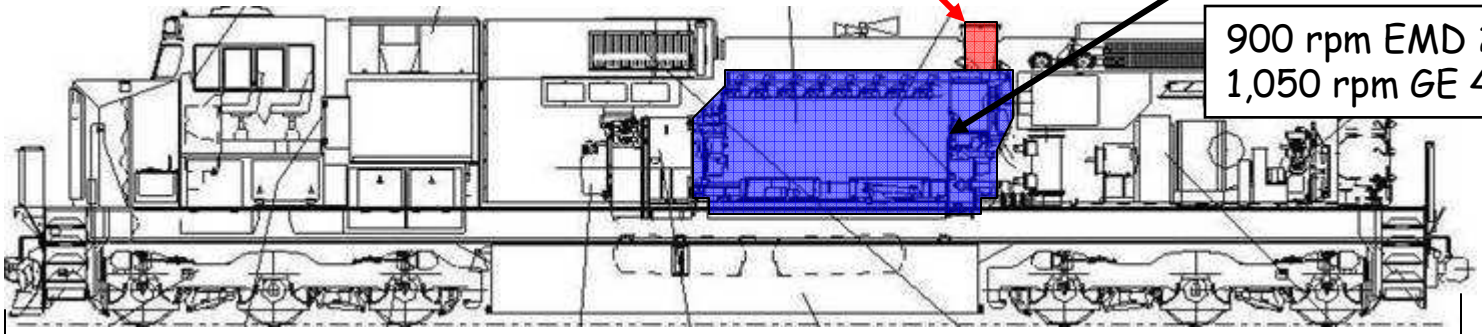
Comparison of Largest US & European Diesel Freight Locomotives

GE *4400 HP* diesel-electric AC locomotive

GE Evolution-series
medium-speed 4400 HP
diesel engine

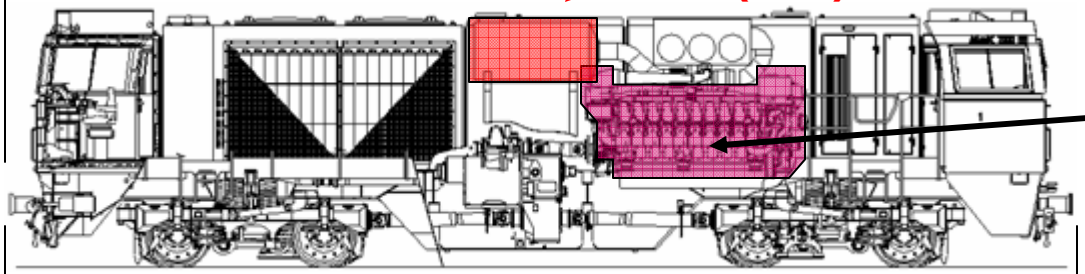
Exhaust muffler

900 rpm EMD 2-stroke
1,050 rpm GE 4-stroke



420,000 pound weight
76' long

Hug diesel particulate
filter (DPF) inside muffler



MTU high-speed
(1,800 rpm) 3,600 HP
diesel engine

200,000 pound weight
57' long

Vossloh MaK 2000BB *3,600 HP* diesel-hydraulic locomotive

Swiss Cargo Am843 Locomotives

* SBB (Swiss Cargo railroad) ordered 73 Vossloh (MAK) 1700 Series Locomotives
* Powered by Cat 3512 diesel engine rated at 1,500 kW (2,000 hp)
  - » 1,500 kW is normal US rating for a 3516 engine, e.g., EMD GP20D
* SBB Cargo required that all new locomotives in this order be equipped with “Soot Filters” (DPF)
* Swiss Cat dealer worked with Hug Engineering and Vossloh to integrate DPF
* No in-use emissions testing performed or required

SBB Cargo operates over 2,300 freight trains daily – an annual total of 9.9 billion tonne-kilometres – serving its customers on a network comprising over 675 delivery points, 600 loading points and 2,450 sidings. In doing so it reduces traffic on Switzerland’s roads and in Europe’s north-south corridor by over 20,000 truck journeys a day.

Source: SBB Cargo 2004 Annual Report

Hug DPF Designed Into New Locomotive Carbody

Housing for MAK 1700 Locomotive

HUG DPF in MAK 1700 car body

SBB Cargo - DPF

- 73 - MAK 1700 locomotives delivered to SBB so far
  - » All equipped with Hug DPF
- Initial delivery units had almost 2 year of operating experience
  - » SBB reports no significant problems with DPF
  - » Hug monitoring backpressure which indicates need for ash cleaning
  - » Cat 3512 engines using synthetic, low ash lubrication oil to minimize ash loading of DPF
- No UIC emissions test results performed on engine + DPF
  - » DPF application voluntary
  - » Actual DPF efficiency unknown but assumed to be high

Principal activities in 2002/2003

Air pollution from suspended particles: The Swiss Agency for Environment, Forests and Landscape, working together with SBB, carried out comprehensive measurements of suspended particle concentrations. The results are gratifying: Rail operations emit significantly less PM10 than had previously been assumed. Only the air in the underground Museumsstrasse Station in Zurich exhibited a much higher concentration of suspended particles than the air in the surrounding area. Since these particles consist primarily of iron, this does not represent a health hazard for either travellers or railway personnel. In 2003, moreover, the SBB ordered 59 diesel locomotives equipped with special particle filters; these locomotives will be used for delivery, shunting and construction purposes. The filters increased the acquisition cost per locomotive by CHF 200,000.

= $169,000

Excerpt from SBB Environmental Report

Hug DPF installed in MAK 1700 Locomotive

SBB Cargo: Summary Observations

* DPF-equipped new locomotives are being produced in selected European markets
* Engine manufacturers supporting DPF installation
* Need not legislatively driven; voluntary and customer specified
* Long-term durability, performance, and maintenance has yet to be established
* DPF service interval will be driven by lubricating oil consumption and lube oil ash level
* No requirement for in-use verification testing in Europe
* U.S. railroads are continuing to closely monitor progress of these DPF-equipped locomotives

Eurotunnel: Existing System Is Not Promising!

Vossloh G1206 locomotive (same as Swiss Am841) without DPF

Water scrubber tender car

Eurotunnel Scrubber Wagon

Eurotunnel

* The Eurotunnel locomotives are moving way from the scrubber wagons
  - » Hug DPF & SCR retrofit
  - » First unit rolled out May 15th
    - – Locomotives are same as Swiss Am841
    - – Work not completed yet
* Mike Iden of UP to provide more details in his presentation

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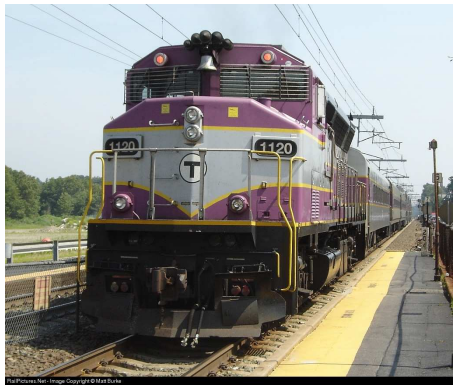
MBTA DOC Demo



Engine could not produce full power
DOC plugged in first 3 weeks of operation & was removed

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California Emissions Program

- Part of CARB diesel toxics reduction program
- CARB looked for a voluntary PM reduction effort from the railroad industry in lieu of greater use of CARB diesel fuel
  - Funded by BNSF & UP railroads
    - $5M budget
  - Scope:
    - PM reduction
    - Switchers
    - California
- CARB interest in a Diesel Particulate Filter (DPF) installed and functioning on a switcher locomotive(s) in California
- Project Managed by TTCI in Pueblo CO.

Background -Approach

- General Technical Approach for CEP program
  - Phase 1 – Laboratory Screening (complete)
    - Task 1: Install EMD 16-645E locomotive engine
    - Task 2: Reduce lubricating oil consumption
    - Task 3: Screen candidate DPF and DOC systems on test engine
      - Evaluated 13 different systems
      - Selected top 3 for 500-hour initial durability test
      - Selected best performer for Phase 2 field implementation
  - Additional details about Phase 1 can be found at: http://www.arb.ca.gov/railyard/ryagreement/071306fritz.pdf
  - Phase 2 – Field Implementation of DPF on Switcher Locomotives
    - Two locomotives retrofitted with DPF systems
      - UPY1378
        - Operational in Oakland Calf
      - BNSF3703
        - Initial operation in San Antonio Texas
        - Awaiting delivery of new DPF formulation and new housing design from HUG

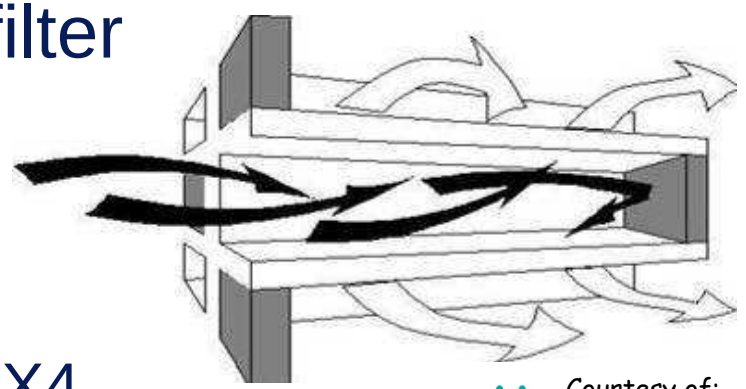
Background – Technology Selected

* Phase 1 of project evaluated 13 different systems on EMD engine installed in SwRI Lab
  - » Both DPF & Diesel Oxidation Cat (DOC) were evaluated
    - – Performance / efficiency at reducing PM emissions
  - » Some of these test components were iterations from a manufacture
  - » A select group of the initial 13 systems were evaluated using a 500 hour durability test

* Results of testing showed that a DPF with a diesel burner offered best trade-off for this application

Background - DPF

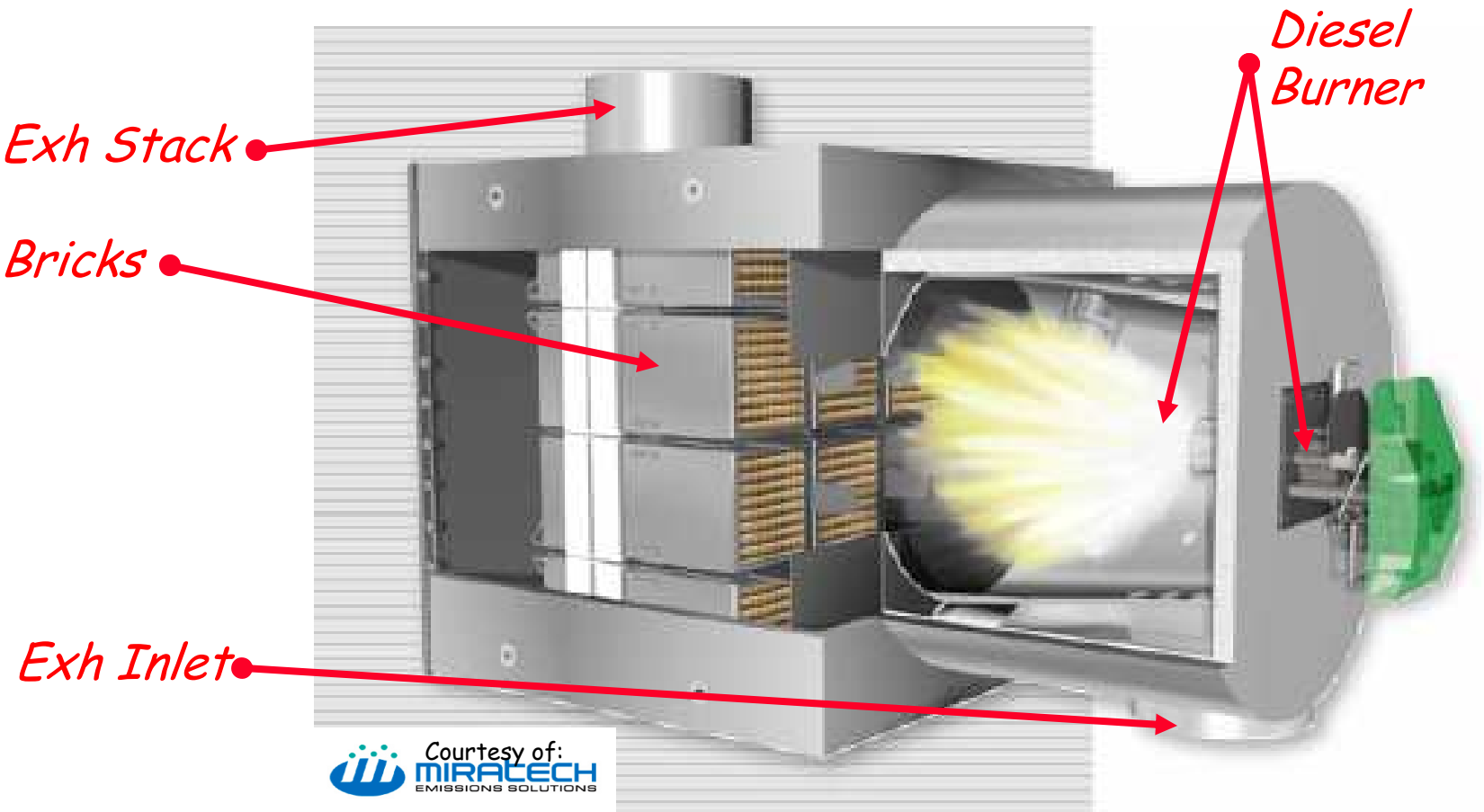
* DPF selected uses wall flow filter
  - » High efficiency
* Phase I DPF had 3X3 brick matrix for 4 cylinders
  - » Demonstration units have 2 – 4X4
    - – Extended maintenance interval



Courtesy of: MIRATECH EMISSIONS SOLUTIONS

Background - DPF

* DPF has diesel burner
  » Needed to provide adequate temperature for regeneration of DPF



Demonstration Locomotives

BNSF3703

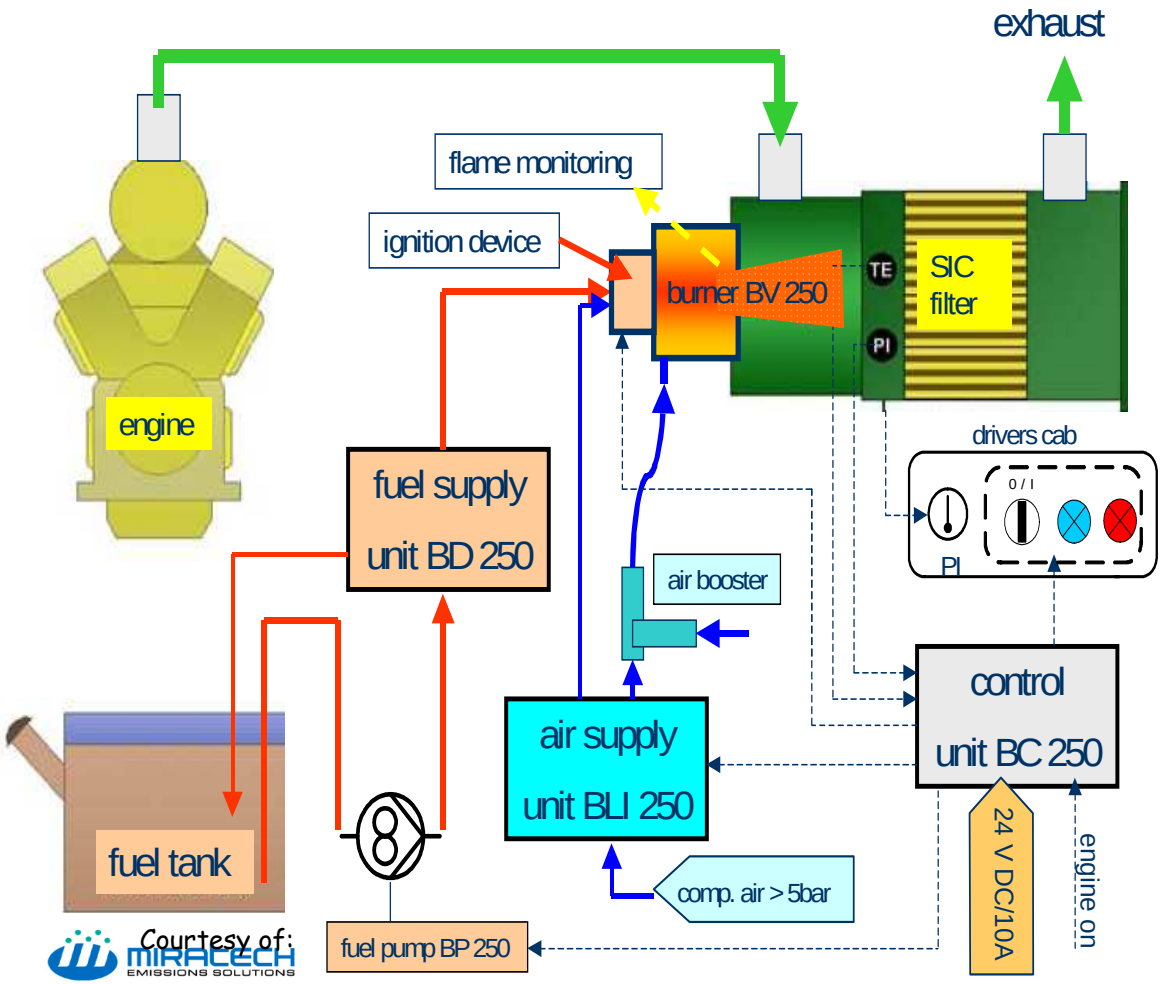
- Released from overhaul on 30-JUN-06
- Equipped with idle reduction system:
  - Diesel driven heating system
  - Idle reduction system coupled to DDHS

UPY1378

- Overhauled in Fall 2005
- Routed to SwRI in Feb. 2006 for DPF mounting design concept meeting
- Equipped with idle reduction system

DPF Installation Considerations

* DPF system needs connection to:
  - » Exhaust
  - » Diesel fuel
    - – Supply
    - – Return
  - » Compressed air
    - – Filtered
  - » 74VDC electrical system
    - – DC-to-DC converter to 24VDC
* SwRI DataLogger system
  - » Monitors
    - – Pressures
    - – Temps
    - – Engine speed
    - – Barometer
    - – Location (GPS)
    - – Battery voltage

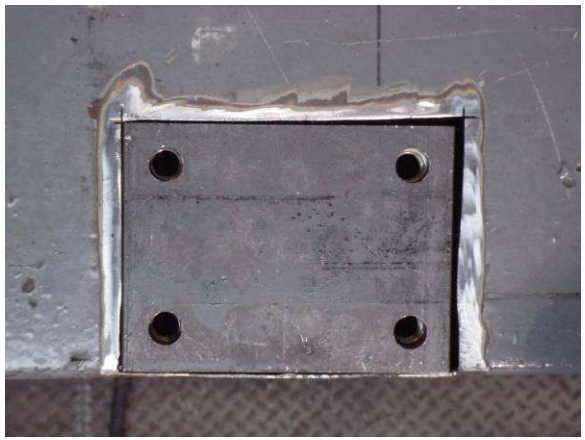


DPF Installation Considerations
Legs

* The rigid box roof and wall at back of MG room on UPY1378 allowed:
  - » 6 legs
    - – Only run to top of roof sill
  - » Legs had bolt pads at top
    - – Pads welded flush with MG room roof
    - – Frame holding DPF's bolted to pads
  - » 2 Legs passed through the air filter housing
    - – Requiring 100% weld to assure sealing of filter housing
* Note that the DPF's weigh a total of 2,280 pounds

DPF Installation Considerations
Legs (cont'd)

* Hole cut in roof
  - » Including air filter housing
* Legs welded to roof
  - » Top
  - » Inside



DPF Installation Considerations Legs (cont'd)

* BNSF3703 required legs to run to bottom sill plate
  - » Legs required bracing
    - – Lack of rear wall
    - – Long legs
  - » Roof modification required to allow access to blowers
  - » Some additional modification to long hood body required to access bolts

DPF Installation Considerations
Frame

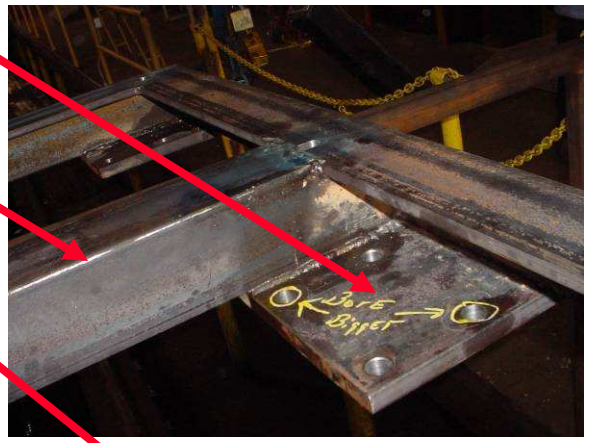
* Build frame out of 4” X 4” X ½” angle
  - » Cross member to support filters
  - » Gussets under angle for support
  - » Holes & Slots cut in frame
    - – For mounting DPF’s
    - – Must allow for thermal expansion
* Bolt pads
  - » 6” X 8” X ¾” plate
  - » 4 - ¾” NC Grade 8 bolts
  - » Bolts drilled & tie wired

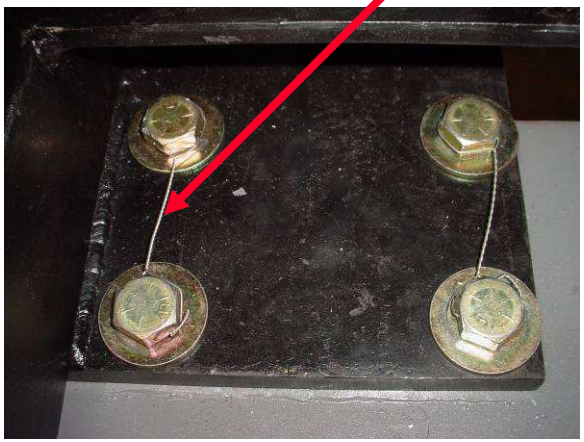
Mounting Pad

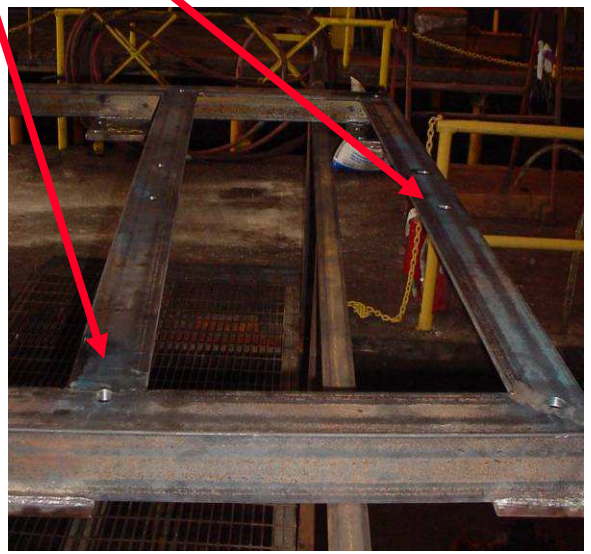
Cross Member

Holes & Slots

Tie Wire Bolts

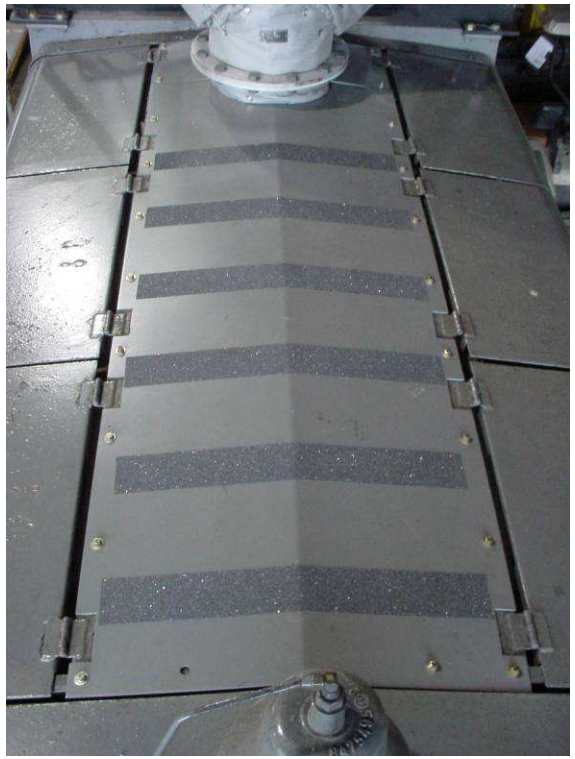






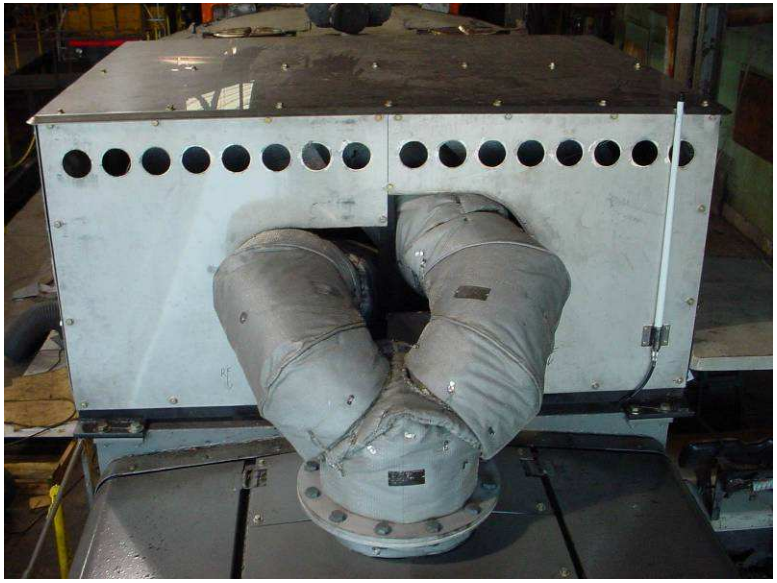
DPF Installation Considerations Exhaust

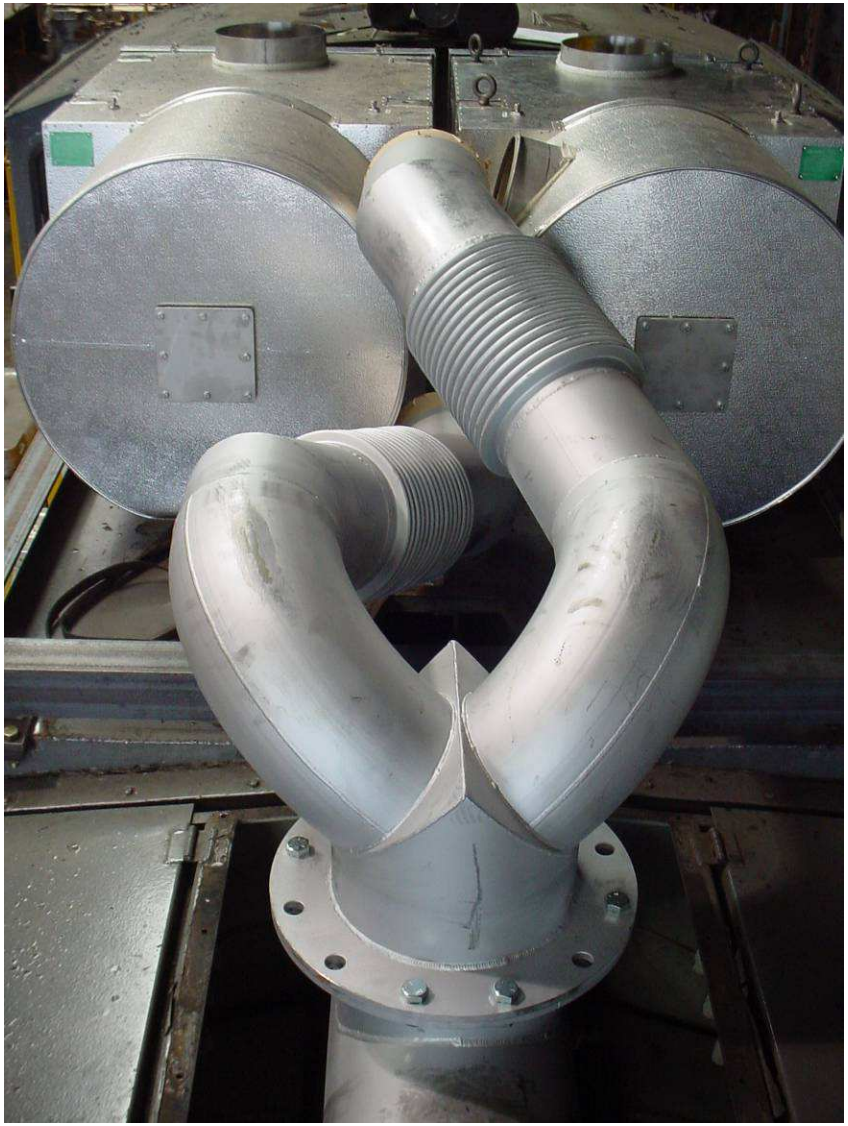
* Standard dual stack manifold replaced with marine single stack
  - » Flange mount on outlet
  - » Roof modified to accommodate manifold
    - – Anti-skid material added to roof at request of FRA
  - » Manifold insulated



DPF Installation Considerations Exhaust (cont'd)

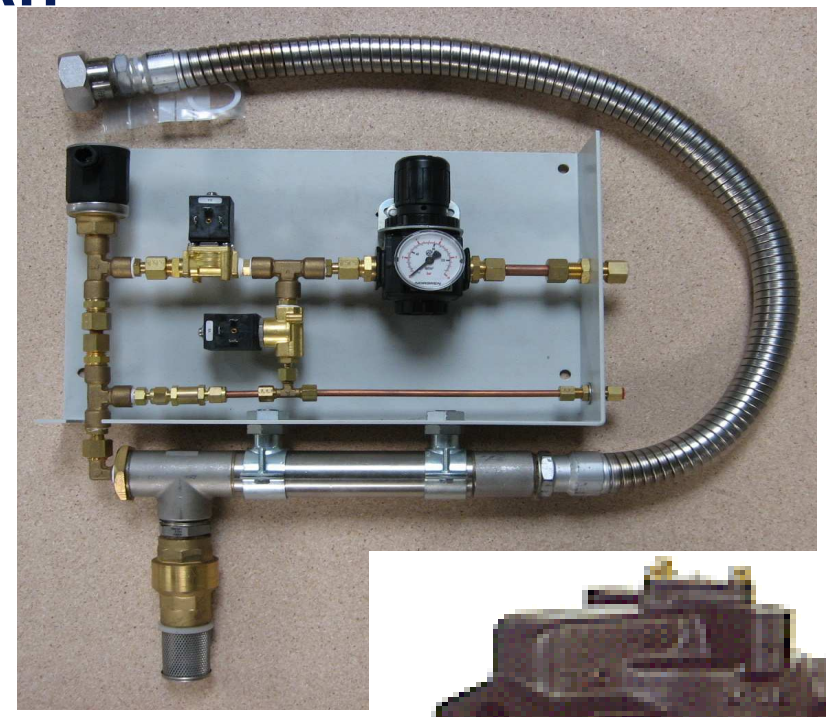
* Custom built exhaust pipe connects manifold outlet to DPF inlets
  - » Pipe is also insulated to retain exhaust heat





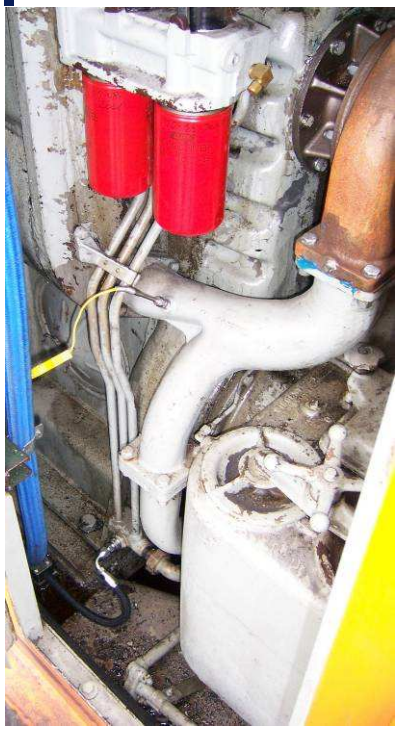
DPF Installation Considerations
Air

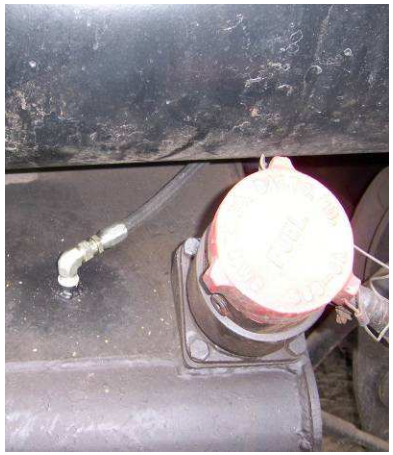
* Air Supply = Locomotive's Main Air Reservoir (MR)
  - » Needs to be clean & dry
    - – Installed dedicated Graham-White Dual Stage Filter
  - » Plumb from MR to dryer and then to air handling system
    - – System on AuxGen mounting frame
    - – Directly above HUG Controller
  - » Air lines run from air handling system to burner



DPF Installation Considerations Fuel

* Fuel supply for DPF system
  - » Comes directly from engine return fuel line
  - » System has 24VDC fuel pumps to supply pressure to burner
  - » Fuel system valves & pressure regulator mounted above engine's roots blowers
  - » Return fuel line to top of locomotive tank



DPF Installation Considerations
PLC

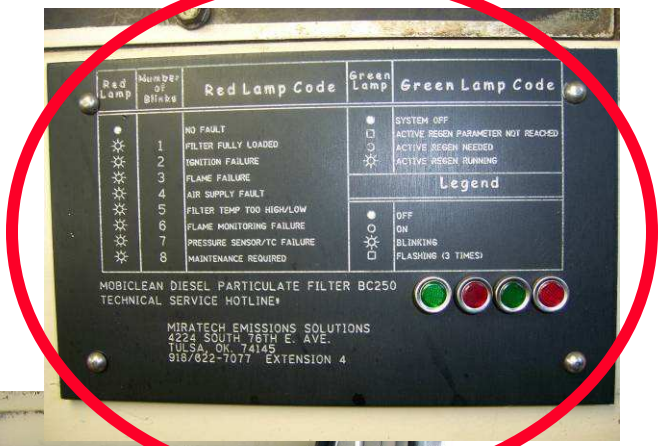
* PLC controller
  - » Mounted below air handling system
  - » Mounted on AuxGen frame
  - » Supplied with 24VDC power
  - » Connected to all sensors and control valves

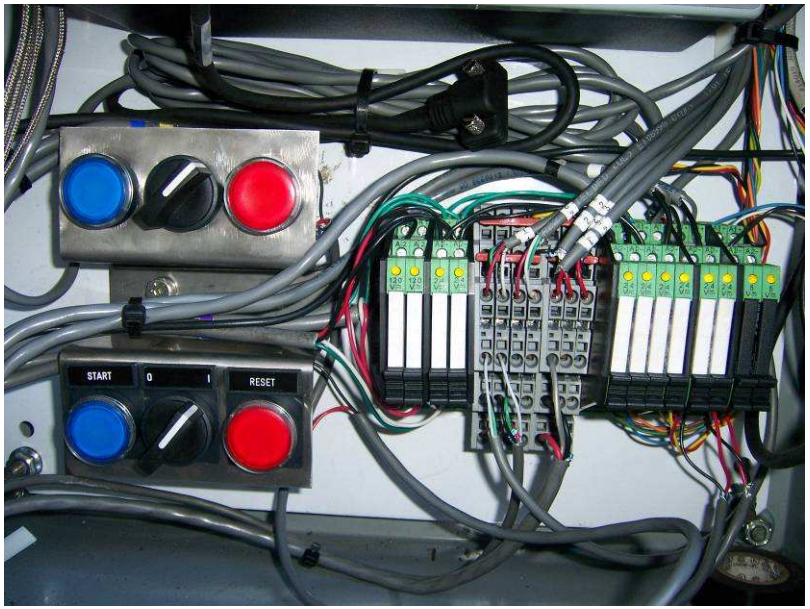
DPF Installation Considerations Locomotive Mods

* Secondary access to top of long hood
  - » Stock access to roof is blocked by DPF system
  - » New steps installed on door @ Left Front of long hood
    - – Door bolted closed
  - » Cover over radiators replaced with serrated bar grate
    - – Per FRA request

DPF Installation Considerations Locomotive Mods (cont'd)

* Placard & lights in cab
  - » Lights to inform operator of DPF status
    - – Green light to indicate regeneration in process
    - – Red light indicates error
  - » Replaces control buttons in Data Logger Box





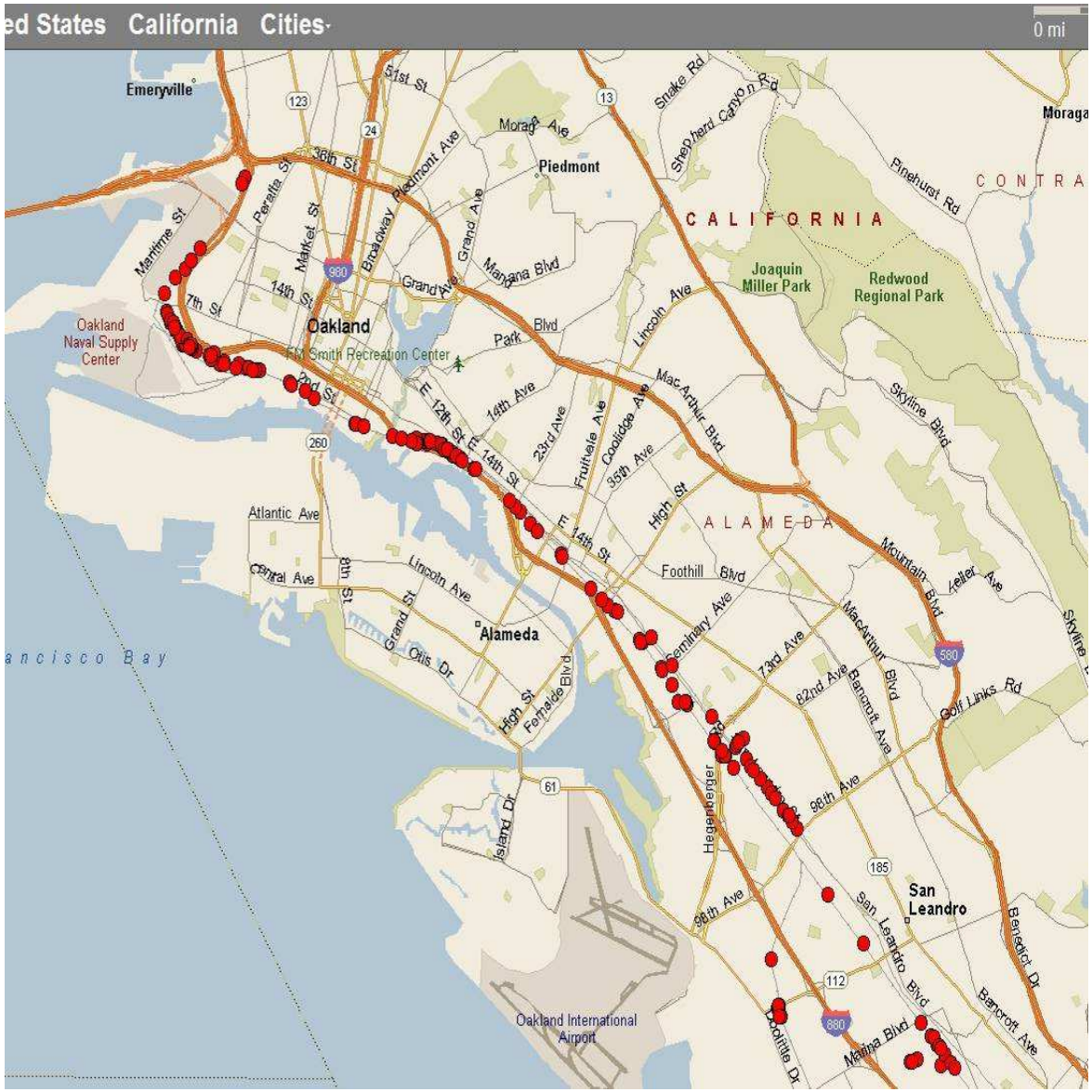
DPF Installation Considerations
SwRI Data Logger

* Campbell data logger
  - » GPS
  - » Cell phone
    - – Fixed IP Address
  - » Monitors
    - – Engine speed
    - – Temperatures
      - Exhaust
      - Burner
      - Jacket water
      - Ambient
    - – Pressures
      - Baro
      - Exh restriction
    - – Battery voltage

Application of Experimental DPF System (cont'd)

Application of Experimental DPF System (cont'd)

* UPY1378 released to revenue service Oct 2006
  - » Working in UP yard in Oakland California
  - » Will return at 12 months to SwRI for additional emissions testing



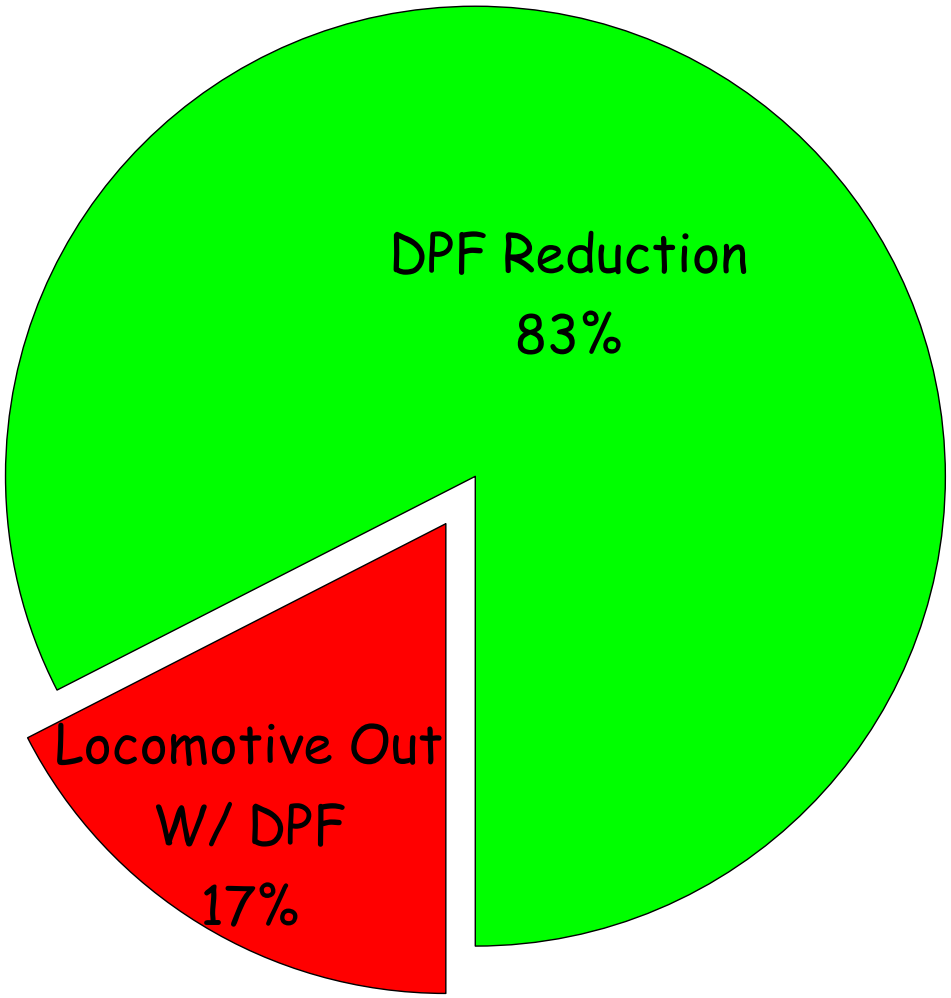
Application of Experimental DPF System (cont'd)

Application of Experimental DPF System (cont'd)

* BNSF3703 has DPF system installed
  - » Working in yard in San Antonio Texas
  - » Waiting delivery from Hug of next generation DPF
    - – Test of new DPF
    - – Then release for revenue service

Application of Experimental DPF System (cont'd)

* Wall flow DPF should provide 90(+) % PM reduction
* Current system on UPY1378 & BNSF3708 are only ~ 83% efficient
* Ongoing work to further reduce PM emissions
  - » New DPF material selections
  - » New ways to pack DPF brick in housing
  - » Add DOC to the system?



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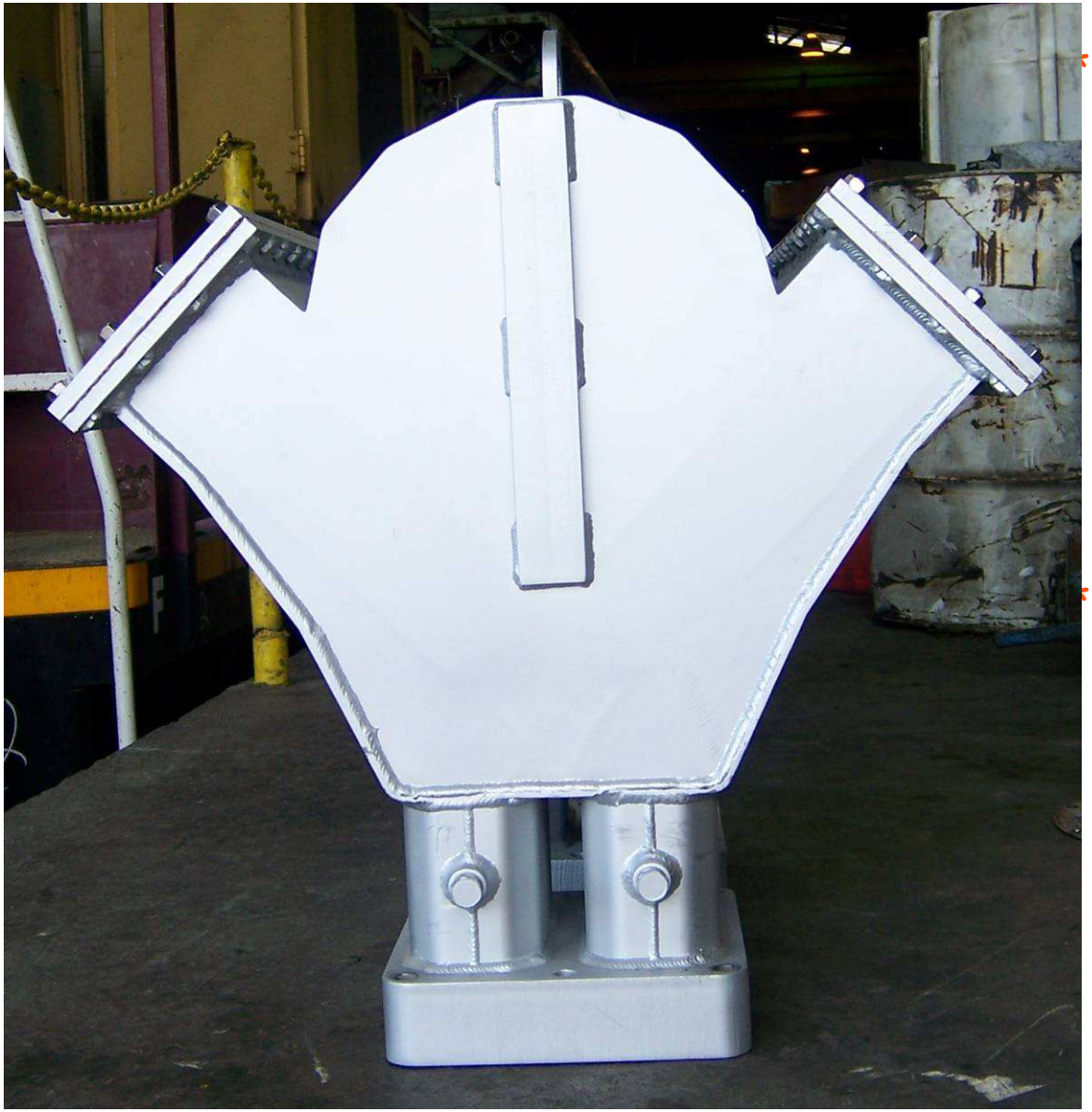
Application of Experimental DOC

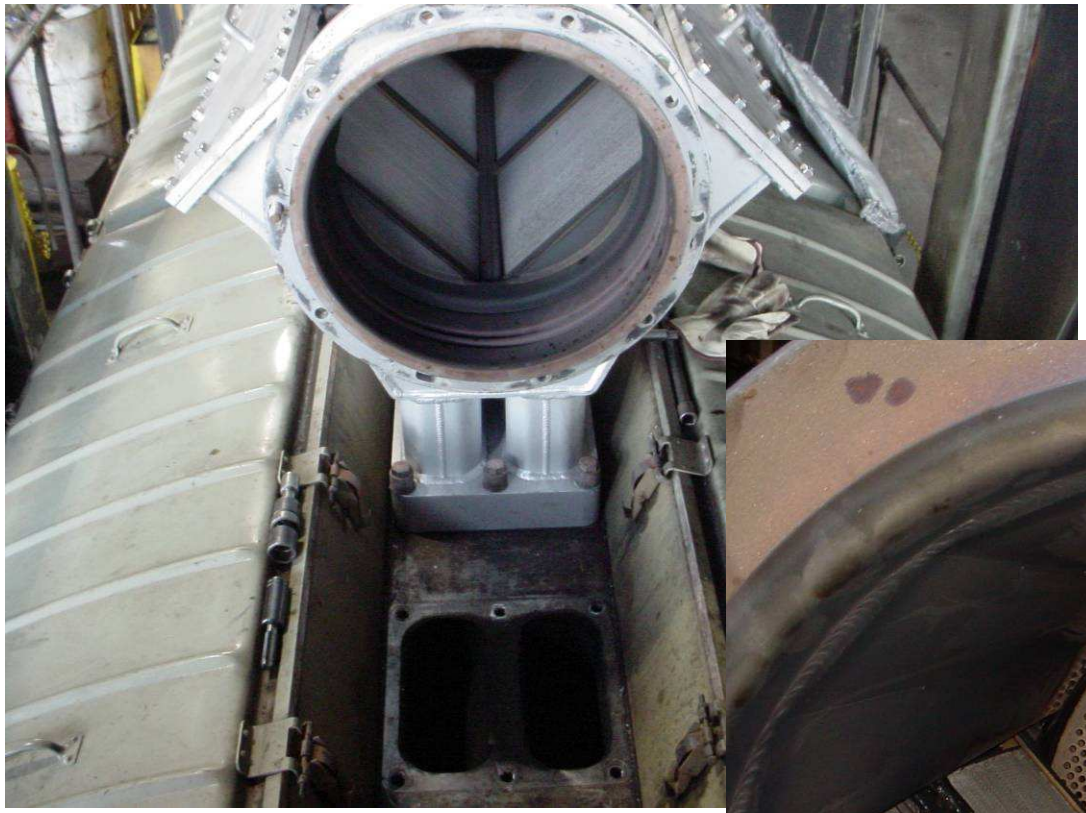
* Experimental DOC installed in EMD SD-60M
  - » Line-haul locomotive
  - » 3,800 traction HP
  - » Turbocharged
* From exterior of locomotive there is no way to tell that DOC system is installed
  - » Novel pre-turbo system
  - » DOC mounted in exhaust manifolds

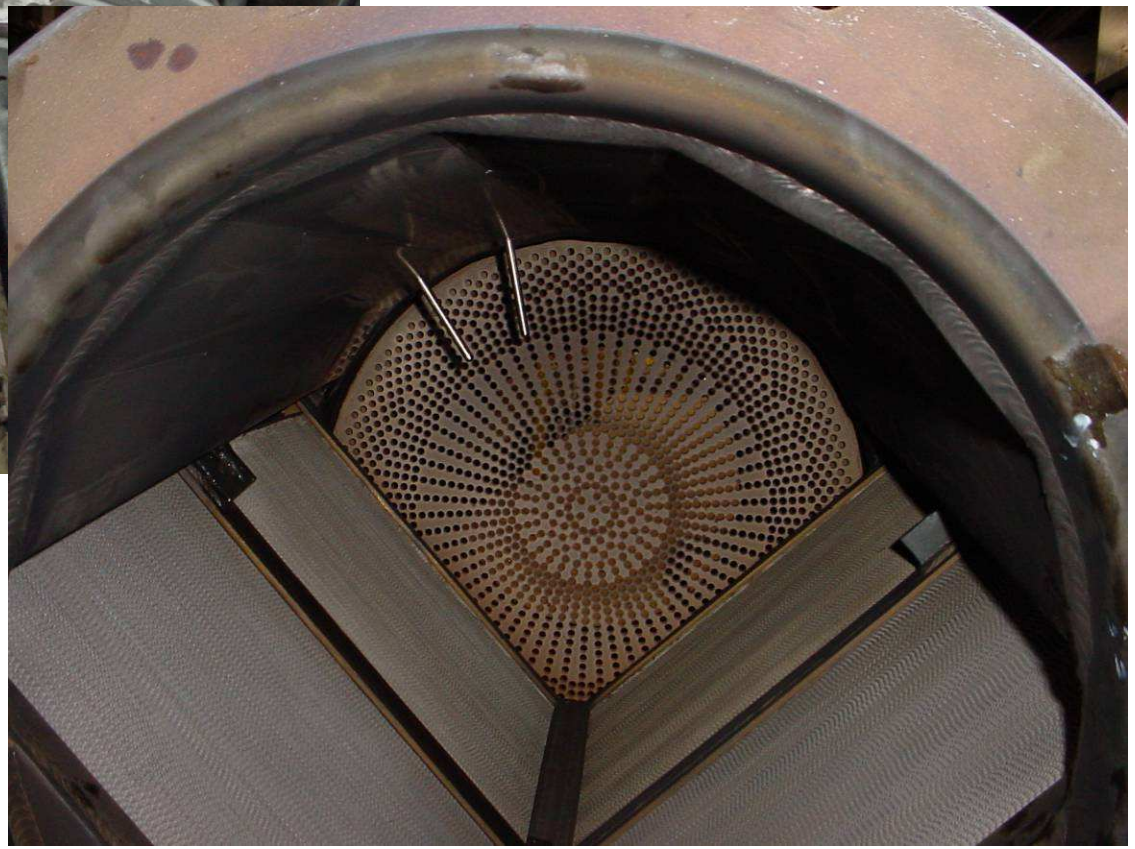
Application of DOC (cont'd)



- Manifolds replaced
  - » Experimental DOC drops into top of manifolds
  - » Design does not hamper engine maintenance / repair
    - – IE: PA removal
- Adds manifold surface area
  - » Requires use of manifold blankets to retain heat
    - – Energy for turbo
    - – Keep long hood cooler

Application of DOC (cont'd)



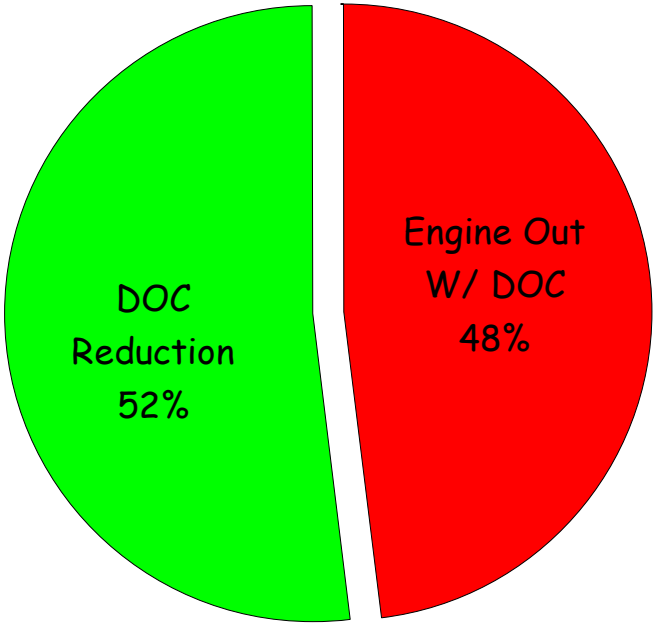


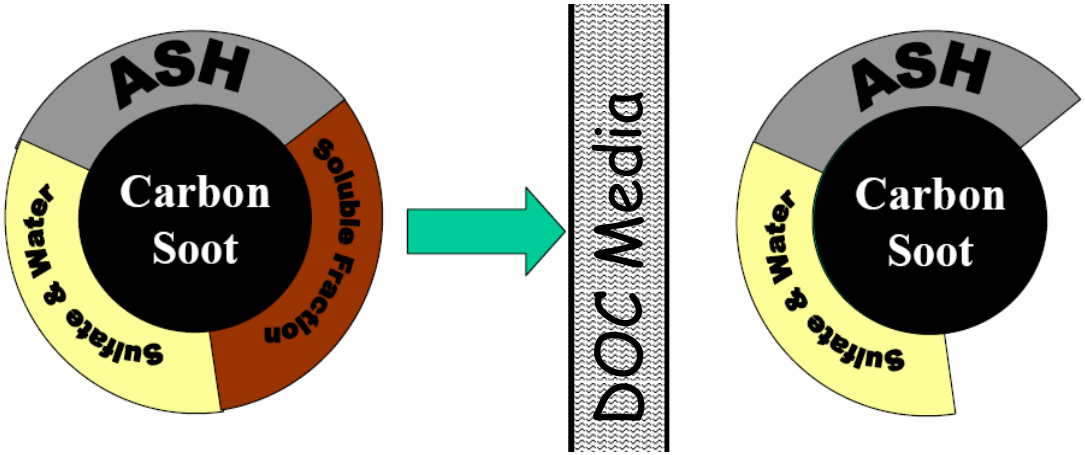
Application of DOC (cont'd)

Application of DOC (cont’d)

Application of Experimental DOC System (cont'd)

* On UP2368 the DOC system reduced PM emissions by 52%
  - » EPA line-haul test cycle
  - » 17 PPM sulfur fuel

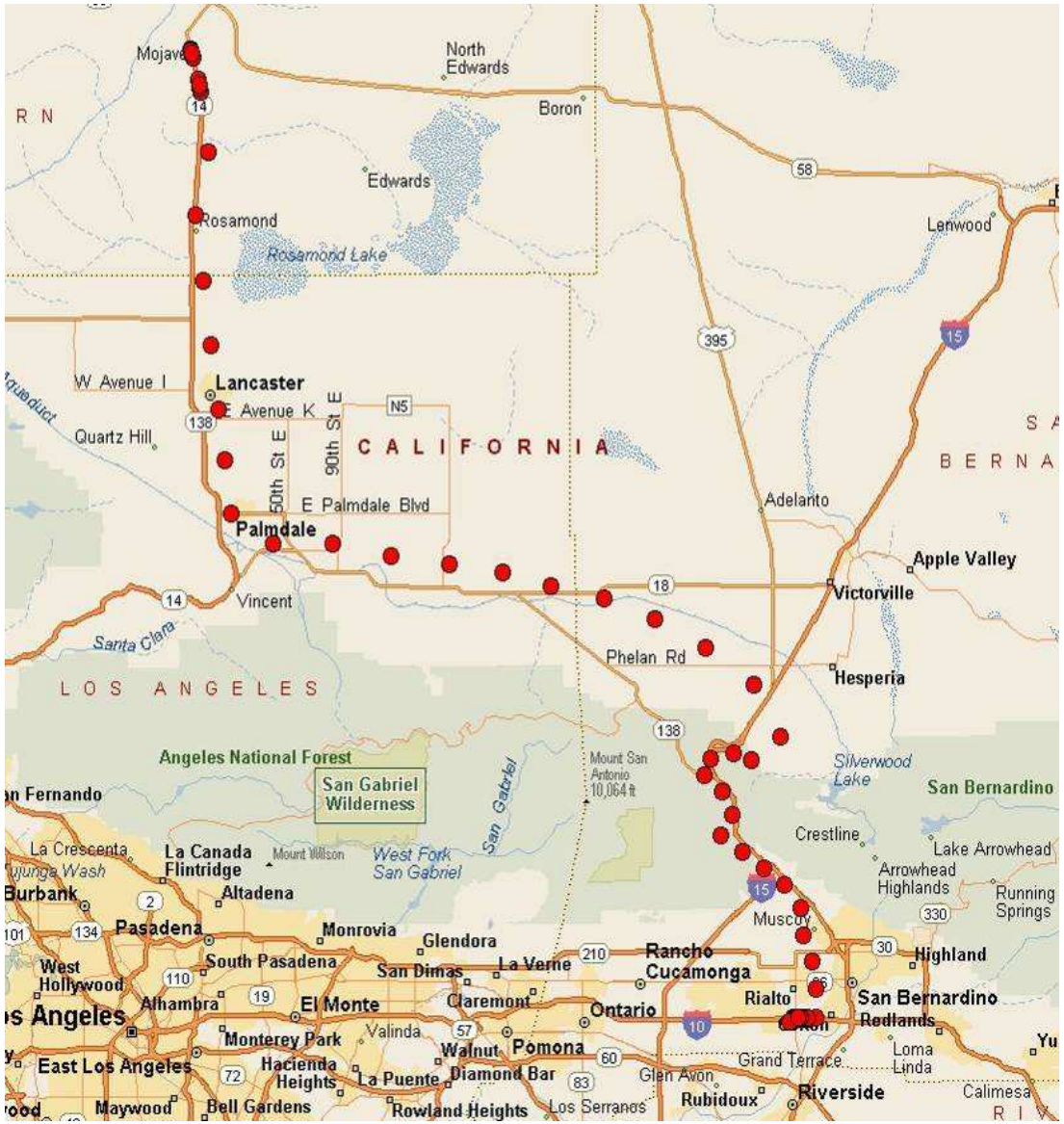




Reference: Osbone, D. T., et.al, "Exhaust Emissions from a 2850 kW EMD SD60 Locomotive Equipped with a Diesel Oxidation Catalyst", ASME Paper JRC-ICE2007-40060, 2007.

Application of Experimental DOC System (cont'd)

* UP2368 released to revenue service Oct 2006
  - » Assigned to helper/hauler service in LA Basin
  - » Inspection of DOC at 3 & 6 months
  - » Final emissions test after 12 months of demonstration



3 Month Inspection of DOC

First the good news:

* No signs of exhaust leaks between manifolds & engine
* The insulation blankets were intact & not oil soaked
* Catalyst elements showed no signs of cracking
* No signs of warping of the manifolds or tracks
* Catalyst gaskets were still in place and tight
* Found DOC to be relatively clean and free of build-up of PM or ash
  - » DOC's were dry (no signs of oil) despite a large amount of time spent at idle
* No debris was found in the turbo screen

Now the bad news:

* Some of the sections of catalyst substrate broke loose from the top side of mantel (outer band) due to exhaust pulse
  - » This allowed substrate to move back and forth about a 1/4 inch
    - – They did not come loose on the bottom
    - – No pieces were lost
  - » This occurred on approximately 4 of the 16 elements.
* Catalyst elements were repaired & re-installed

3 Month Inspection of DOC (cont'd)

6 Month Inspection of DOC

Some bad new to report from the 6 month inspection:

* Repair (post three month inspection) did not hold up
  - » Repair = installing strips of metal welded along the top of the elements to hold the catalyst sections
  - » These strips failed in a number of places, releasing the substrate
  - » None of the catalyst substrate came completely out of the band

Some good news:

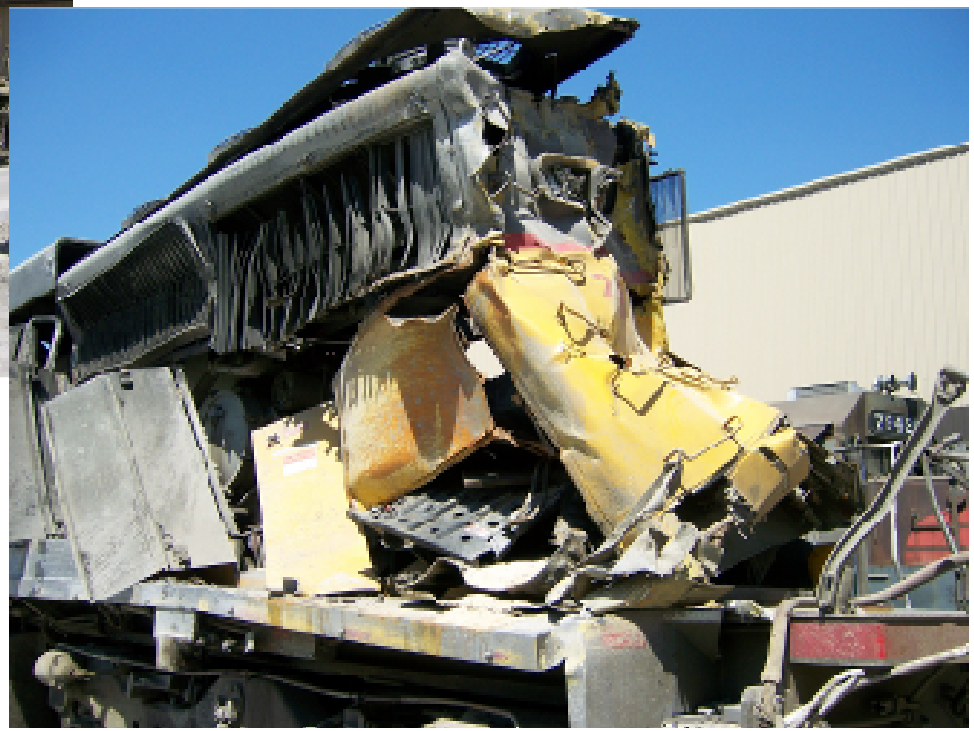
* The exhaust manifolds were still in good shape
  - » No cracks or evidence of leaks
* No oil or contamination buildup on catalyst face

* New designed DOC CAT's are ready to install and continue demonstration

6 Month Inspection of DOC (cont'd)

“The Curse of the Test Locomotive”

* Original test locomotive was UP2448



Bad things can happen with a sample size of one

Outline

* Summary of locomotives fitted with aftertreatment
* Application issues/challenges of installing aftertreatment in US locomotive
* European locomotives equipped with DPF
* MBTA DOC demo
* California Emissions Program (CEP)
* US-EPA / UP program to equip and demonstrate DOC in line-haul locomotive
* Application of SCR to EMD Diesel Engines at Southern California Edison's Pebbly Beach Generating Station at Santa Catalina Island, California

Application of SCR to EMD Diesel Engines at Southern California Edison's

Pebbly Beach Generating Station

Santa Catalina Island, California

By

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Nov. 2004

Background

* TxDOT considering SCR for NOx reduction from Galveston Ferry Operations
  - » Fleet of 5 vessels each running EMD 12-645-E engines
* Question from SwRI to EMD:
  - » Are you aware of any SCR applications on EMD engines?
  - » Answer: Yes, there is one. SoCal Edison using a NOxTECH system on an EMD power generating engines on Santa Catalina Island off of the coast of Los Angeles.
* Lets find out more……

Electrical Power on Catalina

* SoCal Edison provides all electrical power on Catalina Island
* Base load of plant was ~ 5 MW at the time of visit
* Typical “high” load for plant is ~ 6 MW
* Maximum output of the power plant is 9.4 MW

EMD Diesel Power Generation

* Power generated by six EMD diesel fueled engines
  - » 2 Roots blown engines
    - – 16-645
      - Two units
      - Both operate at 900 RPM
  - » 4 Turbocharged engines
    - – 16-567 Operating at 720 RPM
    - – 12-645
    - – 16-645
    - – 16-710

* No two engines are the same age
  - » Engines added as power demands increased

Exhaust Emission Restrictions

- Catalina Island regulated by South Coast Air Quality Management District (SCAQMD)
- An EPA Title V facility
  - Title V permit issued by State and local authorities
    - SCAQMD in this case
  - Title V often called “part 70 permits”
    - Regulations that establish minimum standards for State permit programs are found in 40 CFR part 70.”
  - Additional details can be found at: http://www.epa.gov/air/oaqps/permits/
- To meet emissions permit emissions levels, exhaust aftertreatment was required
  - 70% NOx reduction (typically from 1000 ppm to 300 ppm) for all engines except 710
  - 710 engine required 90% NOx reduction – from 650 ppm to < 51 ppm)
- Currently operating under a PM variance due to application of SCR for aggressive NOx control

Diesel Fuel

- DF-2 used meets CARB Ultra Low Sulfur Diesel Fuel (ULSDF) requirements
  - Used since June 2004
  - Cost premium for ULSDF is ~10%
  - Level of Sulfur in fuel is not constant
    - Thought to be due to contamination during transport
- No know engine related issues by using ULSDF
  - The facility has fuel flow measurement devices on each of the engines that had to be recalibrated after switching to ULSDF
    - Due to higher API gravity of the ULSDF

SCR Emissions Reduction System

* 1995 – Installed NOxTECH NOx reduction system on one 2.8 MW engine
  - » Uses gas-phase reactions to reduce NOx in the temperature range of 1400 to 1550℉ with supplemental burner
  - » Used no catalytic surfaces
  - » Reported 90% NOx reduction
  - » Considered Best Available Control Technology (BACT) by SCAQMD
* 2003-04 Replaced NOxTECH with Johnson Matthey SCR
  - » Installed SCR on all 6 engines
  - » Plant uses Urea as a reagent
  - » Provides very low NO_x levels
* JM Oxidation catalyst used post SCR
  - » Reduces ammonia “slip”
  - » Oxidation cat can also reduce volatile organic fraction in PM emissions
  - » Also reduces Carbon Monoxide

Exhaust System Layout

Note that the entire exhaust system is insulated.

Urea Storage

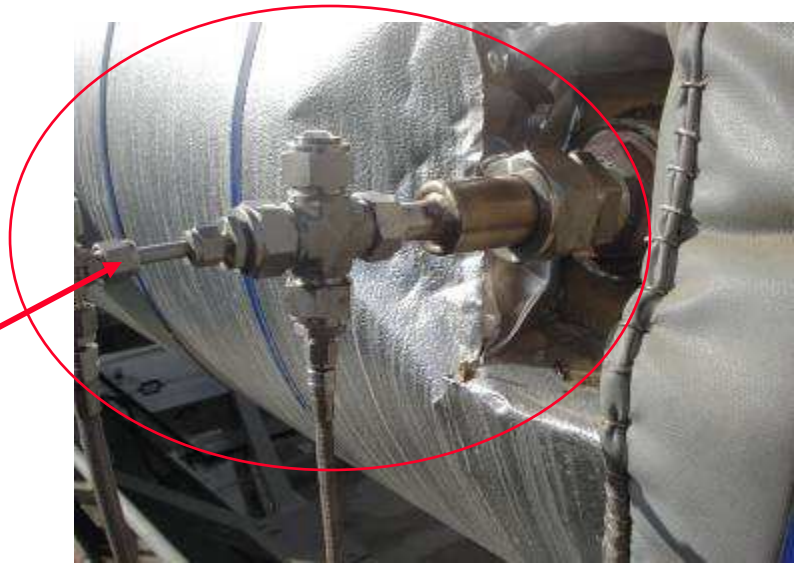
* Urea is delivered to the island in bulk
  - » Delivered as a liquid
  - » No significant freezing issues at this facility
* Two 5000 gallon bulk urea tanks in fuel storage area
* Smaller urea tanks at each engine
  - » JM Control / metering system next to urea tank

Urea Consumption

* Urea consumption rates
  - » 23 gallons per hour for 710 engine
    - – This is approximately 12 to 15% of fuel consumed for a 4,000 hp engine
    - – 9 to 14 gallons per hour for other engines
* Urea costs ~ 1.50 $/gallon
  - » Cost has been increasing at a similar rate to diesel fuel
* Amount of urea injected based on a map in SCR control system
* SoCal Edison reports that current Urea consumption is about 10 to 15% higher than expected

Urea Injector

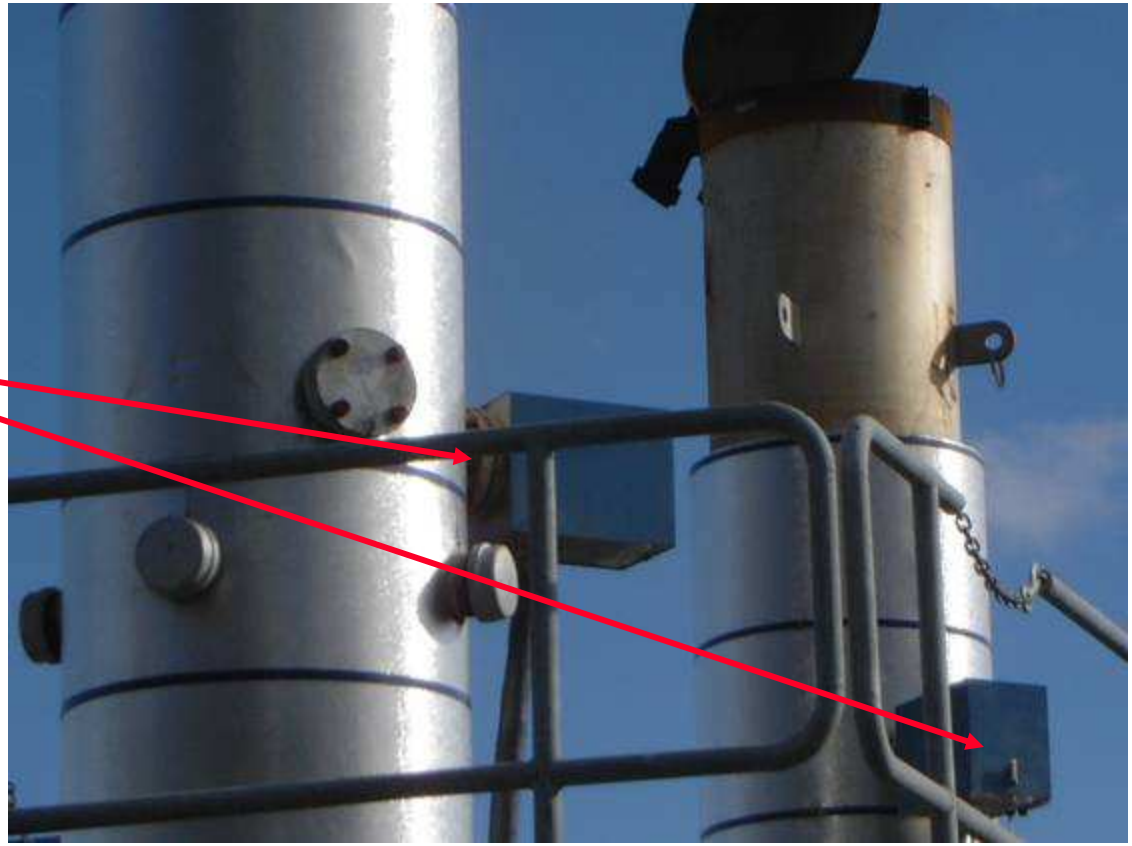
* Urea injected ≈ 15-feet upstream of the SCR catalyst
* Johnson Matthey urea injector
  - » Air-assisted injector used to improve mixing



Continuous Emissions Monitoring

* Emissions from the engine exhaust stack are continuously monitored to assure that power plant emissions are under permitting limits

Emissions sample probe in each exhaust stack

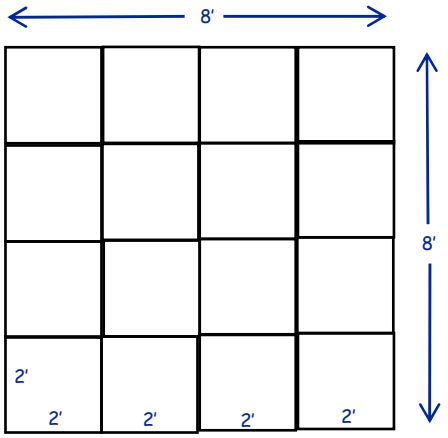


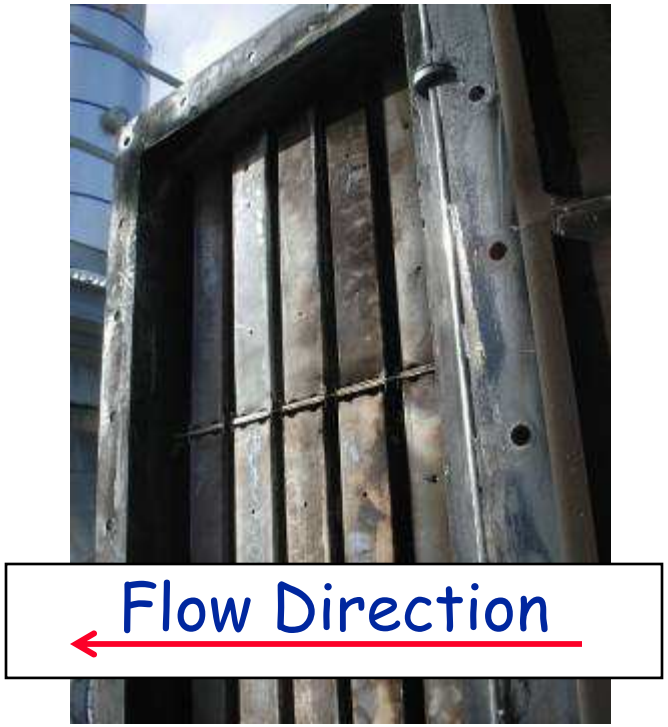
SCR Package

* The SCR package for the 16-710 engine is relatively large
  - » Roughly 8’ X 8’ X 8’
  - » = 512 ft^3 = 78x swept engine volume!
* The exhaust pipe ~ 24” diameter
  - » Plus insulation on outside of pipe
* The oxidation catalysts are mounted as the last row of catalysts elements in the SCR housing
  - » Not in a separate housing

SCR Layout

* SCR housing contains removable catalyst elements that form 5 rows
* First row of elements were originally uncatalyzed when using 200 Cell Per Inch (CPI) elements
  - » First row used to protect more expensive catalyzed elements
  - » First row was replaced with catalyzed elements when SCR was converted to 100 CPI elements
* Last row of elements are the oxidation catalyst

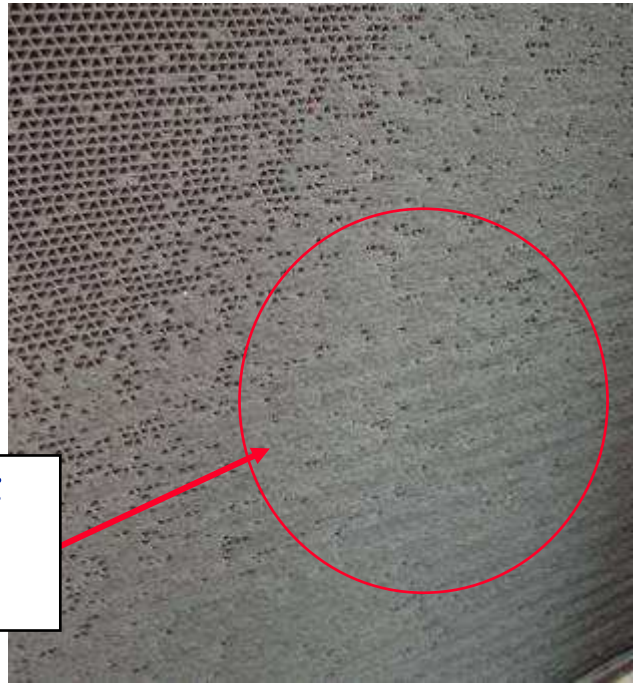




Problem: SCR Catalyst Plugging

* Differential pressure across the SCR system is a major issue and monitored closely, as it affects the backpressure on the engine
* Pressure increases over time
  - » PM starts to block flow through the SCR catalyst
  - » PM is primarily on face of catalyst – surface loading
  - » Need to clean catalyst elements to remove PM
* Issue greatly reduced by converting from 200 CPI to 100 CPI catalyst elements

Pressure Differential measurement



SCR Catalyst Plugging

EMD Backpressure Limits

* Maximum engine exhaust back pressure is set at a very low limit by EMD
  - » 5 to 8 inches of water column on the turbocharged engines
  - » 15 inches of water column on the roots blown engines
    - – The roots blown engines typically plug the SCR faster due to higher PM rates
* Higher back pressure can effect crankcase (CC) pressure
  - » Engine safety trips at -0.8 inch water column CC pressure
  - » Elevated exhaust back pressure on turbocharged engines hits this limit very quickly
  - » Roots blown engines with closed CC not effected

SCR Catalyst Cleaning

* Cleaning of PM from SCR element (to reduce back pressure) requires:
  - » SCR be cool enough to allow staff to handle elements
  - » Staff must be certified to handle hazardous materials
    - – elements coated with vanadium
    - – PM can contain heavy metals and other contaminates
  - » Cleaning for So Cal is performed by a contractor
  - » All material removed from the face of SCR must be disposed of properly
* Cleaning 710 SCR underway during SwRI visit
  - » Dirty pressure drop across catalyst was 1.6 in. H2O
  - » Cleaning reduced this to 0.8 in. H2O
  - » At 1.6 in. H2O, maybe cleaned a little earlier than necessary

Methods to Reduce PM Plugging of SCR Catalysts

* Reducing engine-out PM should increase time between cleanings
  - » SoCal already advanced fuel injection timing to TDC
    - – Injection retard had been used to reduce NO_X but increased PM
    - – Let SCR remove the NO_X , reduce the PM level, and improve fuel economy
  - » SwRI offered additional suggestions:
    - – The use of low oil consumption rings and liners
      - EMD locomotive Tier II ring and liner kits for low oil consumption?
    - – Switch to multi-viscosity lubricating oil to reduce oil consumption
      - use of SAE 20W-40 in place of SAE 40
    - – Switch from 17 TBN oil to 13 TBN, or even lower
      - High TBN oils may not be needed when using low sulfur diesel fuel
      - High TBN oils may have higher ash concentrations which means more ash presented to the SCR catalyst – likely contributor to plugging.
    - – Purge crankcase ventilation post SCR to reduce oil and PM load going into SCR
    - – Future use of a PM filter before the SCR

Initial Engine Start & Warm-Up Issues

* Catalyst warm up a slow process at power plant
  - » Engine and catalyst warmed up for up to one hour before Urea is turned on
    - – Target temps in the catalyst is 550°to 560℉ before urea is injected to exhaust stream
    - – Initial start white smoke
    - – Transitions to black smoke as load is applied, and before turbo and exhaust up to operating temperature
    - – Then Orange/Red/Yellow haze, likely due to NO_2 formation at the oxidation catalyst, until Urea injection starts.
  - » SoCal receives public complaints about smoke during this warm-up period.

Summary

* SCR has been successfully applied to EMD turbocharged and roots-blown engines in power generation applications
  - » SoCal overall happy with performance
  - » Operating well within SCAQMD permit levels
  - » Essentially 1-year of revenue service experience
* Catalyst plugging and cleaning frequency improving
  - » 200 CPI to 100 CPI SCR catalyst made a big improvement
  - » Advanced fuel injection timing back to TDC
* SoCal Edison and JM team very open with information
  - » Especially after they realized we were not trying to sell them anything!

Observations for Rail and Marine

* JM SCR system is very large, at 78 X swept volume
  - » Obvious packing issues on locomotives and vessels
* EMD exhaust back pressure limits drive the need for large SCR package.
  - » Need to assess/understand/engineer solution to enable EMD turbocharged engines to tolerate significantly higher backpressure.
* High engine-out NOx levels mean high Urea consumption rates, and at $1.50/gallon for Urea, this trade-off needs to be considered.

Acknowledgements / Contacts

Special thanks for the cooperation of:

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